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Hydrology and Earth System Sciences Discussions

Interactive comment on "Desiccation-crack-induced salinization in deep clay sediment" *by* S. Baram et al.

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This paper interprets the chemical condition of the vadose zone below a sludge pond to be dominated by processes that occur in the presence of fractures. Fractures permit rainwater infiltration and subsequent evaporation to occur deep in the vadose zone (> 7 m). The repercussions of this mechanism are that evaporation via the fracture system will significantly reduce deep discharge of water from the pond. The solutes that are left behind are transported rapidly during subsequent infiltration events.

The conceptual model is tested using isotopic data for oxygen and hydrogen, and pore water salinity. The experiment was well designed permitting comparison of three sites, each with similar fracture formations, but different liquid input and soil moisture

regimes: sludge pond, margins and natural site. The conceptual model is that pond leakage sustains a moist but not completely saturated subsurface. The lower saturation is able to sustain an open and connected fracture network. Moisture from the pond infiltrates downward slowly through the porous matrix (mm.day), reaches the fractures and keeps the fracture surface moist. Between rain events air invades the fracture system driven by unstable thermal gradients. The drier invading plumes of atmospheric air drive evaporation of the matrix walls into the fracture, causing an accumulation of salts along the fracture walls and an increase in the isotopic signature. During precipitation events, infiltrating rainwater invades the fracture system rapidly (m/hr) and deeply, moving solutes downward.

Below the pond, any increase in the isotopic signature by evaporation is obscured by the high value of the waste water. Thus, the evaporation signature is not distinguishable in the isotopic signature below the pond. However, the salinity data indicates evaporation as a likely mechanism for saline accumulation at these depths. To investigate further the role of evaporation at depth, the authors also look at the isotopic signature below the margins and below the undisturbed site. The margins show high values of the isotopic signature in winter at 6 m depth, indicating one of two sources, either episodic overflow of the pond into the fracture system of the margin (which apparently was shown in their earlier paper) or evaporation at depth from invading atmospheric plumes of dry air – both of these mechanisms are most likely to occur in winter. Differentiating which (or both) of these mechanisms is acting beneath the margins is not possible with just the isotopic data shown. But, the undisturbed site may shed some like on the strength and prevalence of the hypothesized deep evaporation mechanism. The data (Fig. 4) shows a relatively smooth enriched profile with depth and the typical near surface evaporation signature. The smoothness of the profile indicates a cyclic process of deep evaporation and infiltration. The signature is more enriched than the meteoric value but less than the expected near surface evaporation signature. The authors suggest this indicates cyclic enrichment from deep evaporation and dilution from deeply infiltrating water. Because the isotopic signature of groundwater at the site is not reported, the relative contribution to this signature from upward capillary movement is unclear. The oxygen signature shows stronger variability in winter than is summer. This could be explained by deeper evaporation during winter (data taken near end of winter, post rains). The thermal data indicates that summer gradients may be too low to sustain deep atmospheric plume invasion during summer months, especially since the seasonal thermal profile with depth generally reverses during summer to produce a stable thermal gradient. Therefore, from the point of view of deep evaporation driven by atmospheric invasion, it make sense that the winter data would be expected to show more enriched signature locations. That said, is the variability in the del-O data real or within the expected error, considering the same variability (winter) is not seen in the del-H data?

The paper investigates an important phenomenon with large implications for calculations of solute transport below sludge ponds. Solute transport in such a system is immensely complex with a number of mechanisms potentially impacting the ultimate chemical signature. This paper provides a good data set, an analysis that sheds quantitative light on the potential implications to deep drainage, and adds an important contribution to the continuing scientific discussion of mass and energy transport in fracture vadose zones.

Some technical comments.

On page 13163 the authors comment that they assume that the relative humidity of the invading atmospheric air immediately reaches 100% humidity. While assumptions such as this can be used to make first order calculation, it should be clarified for the sake of future readers that in real life evaporation of the fracture is only sustained while the relative humidity of the invading air is less than that of fracture air, and published data (Weisbrod et al., 2009, 10.1029/2008GL036096) shows that relative humidity during air invasion drops significantly within the fracture system.

Sec. 3.3- Thermal gradients. Please clarify the explanation of the data on page 13169-

70. Diurnal changes in the thermal gradients only extend to a limited depth. Below about a meter the thermal gradient changes seasonally. For convective venting to lead to atmospheric invasion, and for atmospheric invasion to proceed downward, what is important is the magnitude and direction of the slope of the gradients that are exhibited at different times of the year. Note that during summer months, the seasonal gradient at your site may not be conducive to deep convection.

This work leads to a potential future project and a very important question: what is the long term pervasiveness of these invading atmospheric plumes? Are these signatures repeated from winter to winter at the same depths? Do the same fractures (that the authors state are pervasive) vent the vadose zone in the same way from one winter to the next? If so, this may have significant implications for the physic-chemical evolution of fracture vadose zones.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 9, 13155, 2012.